HYPERSONIC FLOWS OVER CONICAL BODIES WITH ASYMMETRIC BLUNTNESS

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Investigation of hypersonic flows around bodies with asymmetric nose bluntness with a small asymmetry was carried out basing on a devised program system for calculating super- and hypersonic flows over bodies with various bluntness and experimental data obtained in hypersonic wind tunnels. The Behavior of correlation dependence, due to small asymmetry, between aerodynamic coefficients and parameters of hypersonic similarity was verifed by numerical and experimental data.

Investigation of hypersonic flows and determination of aerodynamic characteristics of bodies with a small asymmetry is connected with examination of high-speed space vehicle (HSV) flight trajectory. This complex task includes simultaneous solution of problems related to dynamics, variation of shape and estimation of the vehicle aerodynamic characteristics during its motion and ablation of heat shielding material (HSM). Determination of the space vehicle aerodynamic characteristics may be divided in two parts:

<u>the first</u> – determination of aerodynamic characteristics for a body with initial (symmetric) configuration in the required variation ranges of Mach number M, flight altitude H and angle of attack A;

<u>the second</u> - determination of aerodynamic characteristics for a body with arbitrary and small enough asymmetry, caused by different physical factors.

There is a set of different techniques devised for solving the first – classic – problem; and transactions, treatises, tables of gasdynamic parameters have been issued.

The authors have also elaborated a program system for calculation of flows around such kind of body [5], which includes programs for calculation of sub- and supersonic flow regions using methods of transition to a steady state and calculation of X-hyperbolic flow region using different modifications of the Godunov method. Viscous effects in this program system are taken into account basing on auxiliary approach of the theory of boundary layer.

Let's consider some peculiarities and aspects of the second problem – determination of aerodynamic characteristics of bodies with a small asymmetry.

In principle, this problem may be solved using the above program system [5]. But in order to get with improved accuracy the aerodynamic characteristics of bodies with a small asymmetry at all portion of the vehicle flight trajectory it will require use of detailed difference schemes and, correspondingly, extra (some times unjustified) computer time consumption. In practice, it is advisable to calculate additional aerodynamic corrections due to a vehicle shape asymmetry using simple expedient methods.

For analysis of general properties of the aerodynamic characteristics for HSV with asymmetry shape let's examine an schematic configuration (Fig. 1), which consists of oblique thin cone with semi-cone angle T_1 and truncated cone with a small semi-cone angle T_2. Aerodynamics of this asymmetric body was investigated both numerically and with the help of experiments in blowdown hypersonic wind tunnel, TSNIIMash.

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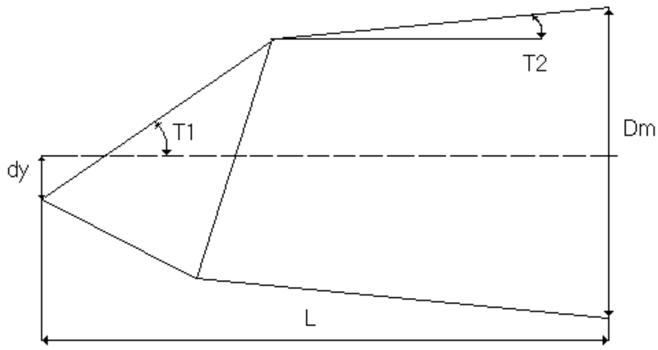

Fig. 1.

Experimental investigation of flows around bodies with a small asymmetry in hypersonic wind tunnels is an individual elaborate problem. First of all it is connected with necessity to measure small forces and moments, acted on a model, especially at zero angle of attack, using

in-model strain-gage balance. Secondly, it is necessary to provide accurate setting of the model angle of attack.

Special measuring technique used worked out to solve this problem, and the tests were conducted at Mach numbers 6 and 8in the hypersonic wind tunnel with good quality of the flow uniformity ($\Delta M/M<1\%$).

Experimental investigations were carried out with the models (schematic is shown in Fig. 1), the front cone has semi-cone angle T_1 = 55°-65° and truncated cone — T_2 = 8°. Asymmetry of the front bluntness is characterized by a value d_y/L=0.02-0.03.

The typical experimental flow patterns for Mach number M = 6; 8 are presented in Fig. 2.

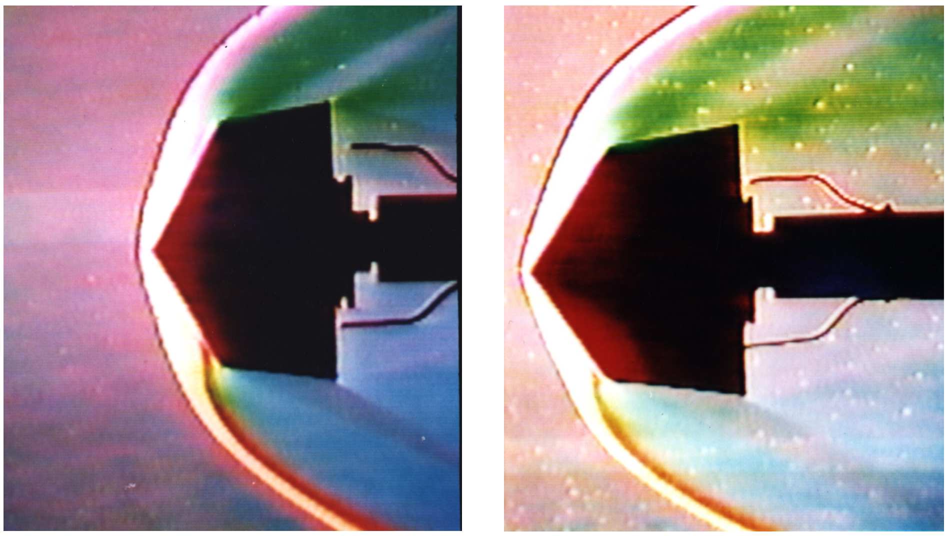

Fig. 2.

The expedient method for estimation of forces and moment acted on bodies with small asymmetric bluntness is based on assumption that at small angles of attack $\alpha \le 10°$:

$$C_y = C_y^{\alpha=0} + C_y^o, m_z = m_z^{\alpha=0} + m_z^o, \tag{1}$$

here C_y, m_z – lift and moment coefficients of asymmetric configuration at $\alpha \neq 0$, $C_y^{\alpha=0}, m_z^{\alpha=0}$ – lift and moment coefficients of asymmetric configuration at $\alpha = 0$, C_y^o, m_z^o – lift and moment coefficients of symmetric configuration at $\alpha \neq 0$. The point of interest is agreement between accurate calculation of C_y and C_y value obtained through the formula (1), and also comparison of experimental and calculated data on C_x and m_z.

Results of the comparison are presented in Tables 1, 2 for the space vehicle with asymmetric conical nose part (semi-cone angles are $T_1 = 61°$ and $T_2 = 8°$, relative displacement of the axis of symmetry of the front cone part, its length and diameter are $\delta_y = 0.0191$, L = 1.27, $D_m = 2$).

Table 1 presents experimental and calculated values of the coefficient C_x and Table 2 – values of the coefficients C_y, $C_y^{\alpha=0}$, C_y^o – in accord with (1).

Calculated and experimental data are in a good agreement for all above cases.

Table 1

M	α, degree	C_x, experiment	C_x, calculation
4	0	1.267	1.142
4	4.68	1.247	1.140
6	0	1.219	1.192
6	3.68	1.208	1.188
8	0	1.233	1.205
8	4.15	1.231	1.197

Table 2

M	$C_y^{\alpha=0}$	α, degree	C_y^o	C_y, $\alpha=1°$	C_y, $\alpha \neq 0$
4	-0.0130	4.68	0.437	0.0307	0.0305
6	-0.0124	3.68	0.0305	0.0181	0.0175
8	-0.0122	4.15	0.0326	0.0204	0.0198

The transverse moment M_z for bodies with a small asymmetry of front bluntness may by estimated by the following way:

$$M_z = (M_{z0}\frac{L}{L_1} - C_{y0} X_T)\frac{S_M}{S_{M1}} \tag{2}$$

here X_T – the coordinate of the center of oscillations, S_M – midsection area of the space vehicle; index 1 is related to the whole vehicle geometry, and dimensions of its nose part have no indices.

Such approach does not include interference of asymmetric front bluntness with the body side surface, and this may cause noticeable errors. This problem was investigated in [6], and similarity law was formulated there for bodies with asymmetric front bluntness.

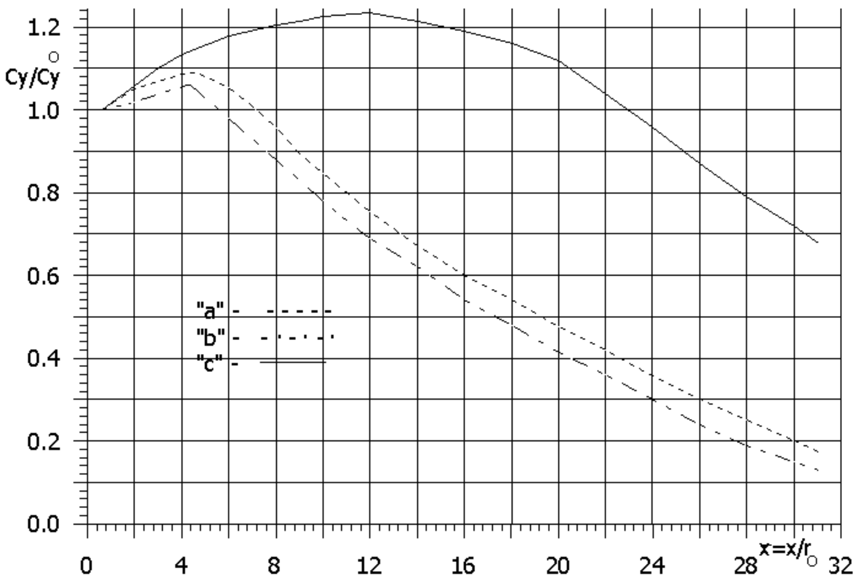

Fig. 3.

Figure 3 illustrates comparison of experimental and calculated data for the above configurations at X = 0.55; 3.92; 9.85; 30 for two values δ_y = 0.02 and δ_y = 0.03 with Mach number M = 6 and 8.

It is seen that calculated and experimental data are in good agreement and correspond to data from [6], A curve with data from [6] is indicated by dotted line. This curve [6] was obtained at M = 20 and specific heat ratio γ = 1.2 This results demonstrate that it is important to take into account physical-chemical conversions for determining forces and moments for the bodies with small asymmetry.

It follows from the plot that for evaluation of M_z value it is necessary to take into account the above interference. And if the interference is neglected, this causes significant errors during calculation of the high-speed space vehicle moment characteristics, and data in Table 3 illustrates this fact.

Table 3

Parameters / Moment coeff.	L^*=0.662 δ_y^*=0.0284 D_m^*=2.0	L^*=1.51 δ_y^*=0.0246 D_m^*=2.0	L^*=2.84 δ_y^*=0.0188 D_m^*=2.0	L^*=4.33 δ_y^*=0.0118 D_m^*=2.0
m_{z0}^H	without interference			
	0.1159	0.0267	0.00295	–0.00085
$m_{z0}^T = m_z - C_{y0} \cdot 0.5$	with interference			
	0.1159	0.0294	0.00555	–0.00045

Here $m_{z0}^H = \left(m_{z0} \dfrac{L_0}{L_M} - C_{y0} \cdot 0.5 \cdot \right) \dfrac{S_0}{S_M}$.

Analysis of data from Table 3 has shown that for the high-speed space vehicle with aspect ratio $X/L \geq 10 - 20$ the values of transverse moment may differ in several times.

Thus application of the local methods for estimating forces and moment acted on the bodies with small asymmetry may cause rather significant errors. The approximate expedient method for calculation of C_y value may be based on the formula (1), and calculating the transverse moment coefficient m_z by this formula it is necessary to take into account the law of hypersonic similarity for bodies with asymmetric front bluntness.

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